

Quark-diquark model for $p(\bar{p})$ - p elastic scattering at high energies

V.M. Grichine^{1a}, N.I. Starkov¹, and N.P. Zotov²

¹ Lebedev Physical Institute, Moscow, Russia

² Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

Received: date / Revised version: date

Abstract. A model for elastic scattering of protons at high energies based on the quark-diquark representation of the proton is discussed. The predictions of the model are compared with experimental data for the elastic differential cross-sections from available databases.

PACS. 4 1.60.Bq , 29.40.Ka

1 Introduction

Recently the TOTEM Collaboration reported the first experimental data on the pp elastic cross-section at a total energy in the center of mass system $\sqrt{s} = 7$ TeV (everywhere the Planck constant, \hbar , and the speed of light, c , are assumed to be unit, $\hbar = c = 1$) [1]. Therefore there is opportunity to describe one in the more wide area of energy using the early data (see, for example, [2]). In general there are the number of models of the elastic pp scattering description [2,3].

In this note we consider the quark-diquark (qQ -) model in which baryons are considered as bound states of quark and diquark (a quasi-particle state of two quarks). This model appeared at the end sixties [4] and was used for description of different problems: baryon spectroscopy [5], multiparticle production [6], deep-inelastic processes [7] and go on. The qQ -model was proposed by V.A. Tsarev [8] in 1979 to describe the characteristics of proton-proton elastic scattering and to explain the absence of second dip in the proton-proton differential cross-section, $d\sigma_{el}/dt$, at the four-momentum transfer $-t \sim 4 - 5$ GeV², which should exist if a proton would compounded of tree quarks.

A. Bialas and A. Bzdak reinvented in 2007 [9] the approach of [8] in more simplified form without the real part of the scattering amplitude. They showed that the quark-diquark model is capable to predict the correct position of the proton-proton differential elastic cross-section minimum, however, the absence of the scattering amplitude real part results in dramatic overestimation of the value of first dip at $-t \sim 1.3$ GeV². The model [9] was applied in [10] to describe at the same level of accuracy the TOTEM data [1] for $d\sigma_{el}/dt$ at $\sqrt{s} = 7$ TeV.

Below we recall the main features of the qQ -model [8] suitable for numerical calculations and provide comparison

with the experimental data on the pp elastic differential cross-section in the region of high energies, $\sqrt{s} \geq 546$ GeV.

2 Quark-diquark model for $p(\bar{p})$ - p elastic scattering

The proton-proton differential elastic cross-section can be expressed in terms of the scattering amplitude $F(s, t)$:

$$\frac{d\sigma_{el}}{dt} = \frac{\pi}{p^2} |F(s, t)|^2, \quad (1)$$

where p is the proton momentum in the center of mass system.

The model [8] limits the consideration of the scattering amplitude by contributions from one- and two-pomeron exchanges between quark-quark (1-1), diquark-diquark (2-2) and quark-diquark (1-2). In this approximation $F(s, t)$ reads:

$$F(s, t) = F_1(s, t) - F_2(s, t) - F_3(s, t), \quad (2)$$

where $F_1(s, t)$ is the scattering amplitude with one-pomeron exchange, while $F_2(s, t)$ and $F_3(s, t)$ correspond to two-pomeron exchanges between the proton constituents, quark and diquark. The amplitude $F_1(s, t)$ reads:

$$F_1(s, t) = \frac{ip\sigma_{tot}(s)}{4\pi} [B_1 \exp(A_{11} t) + B_2 \exp(A_{22} t) + 2\sqrt{B_1 B_2} \exp(A_{12} t)], \quad (3)$$

where $\sigma_{tot}(s)$ is the total proton-proton cross-section. The coefficients B_1 , and B_2 parametrize the quark-quark, σ_{11} , and the diquark-diquark, σ_{22} , cross-sections, respectively:

$$\sigma_{11} = B_1 \sigma_{tot}(s), \quad \sigma_{22} = B_2 \sigma_{tot}(s).$$

^a Corresponding author, e-mail: Vladimir.Grichine@cern.ch

The model assumes the quark-diquark cross-section, $\sigma_{12} = \sqrt{\sigma_{11}\sigma_{22}}$.

The coefficients A_{jk} , ($j, k = 1, 2$) are derived taking into account the Gauss distribution of quark and diquark in proton together with the standard Pomeron parametrization. They read ($s_0 = 1 \text{ GeV}^2$):

$$A_{jk} = \frac{r_j^2 + r_k^2}{16} + \tilde{\alpha} \left[\ln \frac{s}{s_0} - \frac{i\pi}{2} \right] + \lambda \left[\left(\frac{m - m_j}{m} \right)^2 + \left(\frac{m - m_k}{m} \right)^2 \right]. \quad (4)$$

Here r_1, m_1 are the quark radius and mass, and r_2, m_2 are the diquark radius and mass, respectively; $\tilde{\alpha} = 0.15 \text{ GeV}^{-2}$ is the Pomeron trajectory slope, and $\lambda = r^2/4$, where r is the proton radius. In the model it is assumed that the $m_1 = m/3$ and the $m_2 = 2m/3$, where m is the proton mass. The r_1 and r_2 were found by the fitting of experimental data: $r_1 = 0.173 r$, $r_2 = 0.316 r$.

The amplitudes $F_2(s, t)$ and $F_3(s, t)$ are:

$$F_2(s, t) = \frac{ip}{4\pi} \frac{B_1 B_2 \sigma_{tot}^2(s)}{8\pi(A_{12} + 4\lambda/9)} \cdot \left[\exp \left(\frac{A_{11}A_{22} - (4\lambda/9)^2}{2(A_{12} + 4\lambda/9)} t \right) + \exp \left(\frac{A_{12} - 4\lambda/9}{2} t \right) \right], \quad (5)$$

and:

$$F_3(s, t) = \frac{ip}{4\pi} \frac{\sqrt{B_1 B_2} \sigma_{tot}^2(s)}{4\pi} \left[\frac{B_1}{A_{11} + A_{12} - 4\lambda/9} \cdot \exp \left(\frac{A_{11}A_{12} - (2\lambda/9)^2}{A_{11} + A_{12} - 4\lambda/9} t \right) + \frac{B_2}{A_{12} + A_{22} + 2\lambda/9} \exp \left(\frac{A_{12}A_{22} - (\lambda/9)^2}{A_{12} + A_{22} + 2\lambda/9} t \right) \right], \quad (6)$$

respectively. The quark-quark cross-section, σ_{11} and the proton radius r are the free parameters defining (together with $\sigma_{tot}(s)$) the s -dependence of the $d\sigma_{el}/dt$. The diquark-diquark cross-section and the parameter B_2 are derived from the optical theorem, which results in the following equation:

$$\sigma_{tot} b_1 B_1 B_2 + \sigma_{tot} \sqrt{B_1 B_2} (b_2 B_1 + b_3 B_2) = B_1 + B_2 + 2\sqrt{B_1 B_2} - 1, \quad (7)$$

where

$$b_1 = \frac{1}{4\pi} \text{Re} \left[\frac{1}{A_{12} + 4\lambda/9} \right],$$

$$b_2 = \frac{1}{4\pi} \text{Re} \left[\frac{1}{A_{11} + A_{22} - 4\lambda/9} \right],$$

$$b_3 = \frac{1}{4\pi} \text{Re} \left[\frac{1}{A_{12} + A_{22} + 2\lambda/9} \right].$$

Equation (7) is the third-order equation relative to $\sqrt{B_2}$. For $0 < B_1 < 1$, it has rational root $0 < \sqrt{B_2} < 1$ which is used in the model.

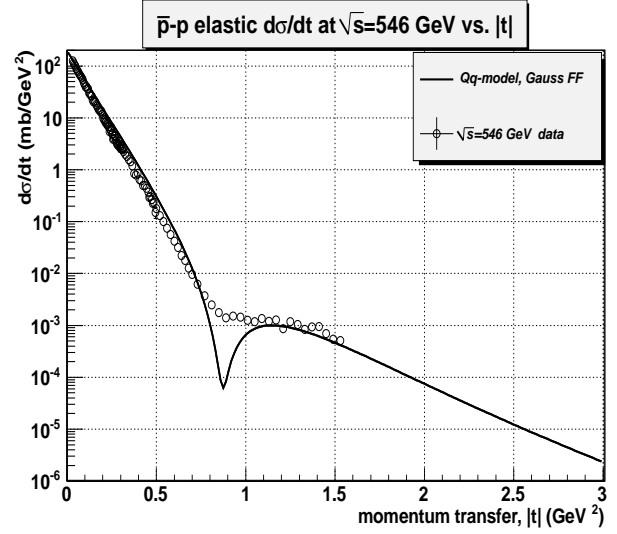


Fig. 1. The antiproton-proton differential elastic cross-section versus $|t|$ at $\sqrt{s} = 546 \text{ GeV}$. The curve is the prediction of our model. The open circles are the experimental data [11].

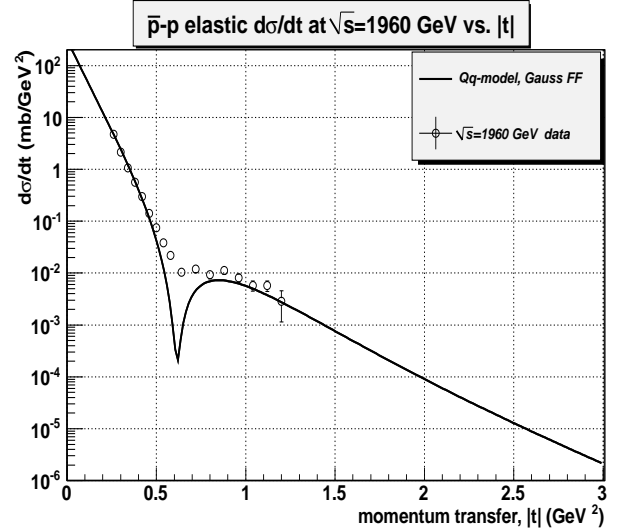


Fig. 2. The antiproton-proton differential elastic cross-section versus $|t|$ at $\sqrt{s} = 1960 \text{ GeV}$. The curve is the prediction of our model. The open circles are the experimental data [12].

3 Comparison with experimental data

Fig. 1,2,3 show the antiproton-proton differential elastic cross-section versus $|t|$ at $\sqrt{s} = 546 \text{ GeV}$, $\sqrt{s} = 1960 \text{ GeV}$, and the proton-proton differential elastic cross section at $\sqrt{s} = 7 \text{ TeV}$, respectively. The curves are the predictions of our model. We see that the proposed qQ -model describe reasonably the differential elastic cross sections of the elastic antiproton-proton and proton-proton scattering in wide region of energy.

The results shown in fig.1-3 correspond to the s -dependence of the model free parameters which are shown in fig.4-5. The model results in increase of the proton radius and the quark-quark cross-section with growth of s .

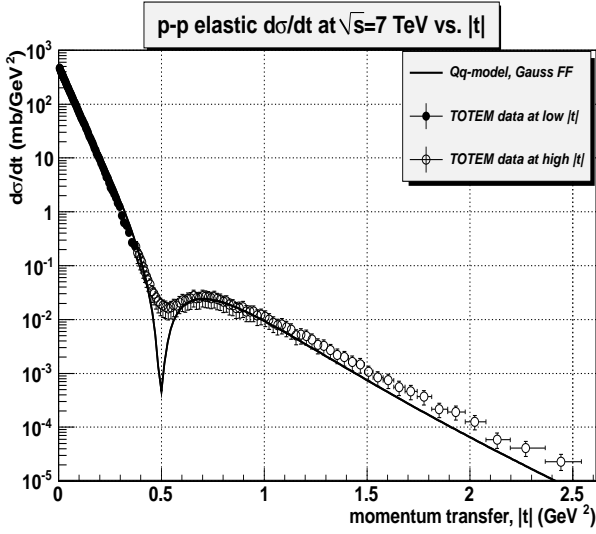


Fig. 3. The proton-proton differential elastic cross-section versus $|t|$ at $\sqrt{s}=7$ TeV. The curve is the prediction of our model. The open and closed circles are the LHC TOTEM experimental data from [1].

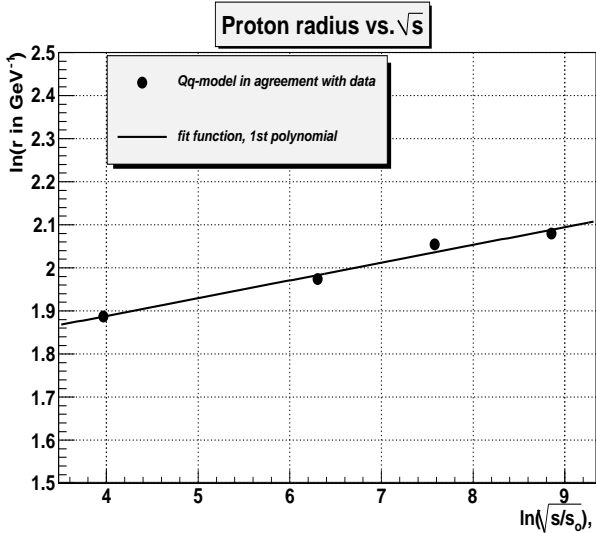


Fig. 4. The dependence $\ln(r)$, r in GeV^{-1} , versus the $\ln(\sqrt{s/s_0})$.

4 Discussion and Summary

We have considered the qQ -model of the pp -elastic scattering at high energies. We have obtained reasonable description of the differential cross section of elastic pp scattering in wide region of energies. The position of the $d\sigma_{el}/dt$ -minimum is in for the satisfactory agreement with experimental data, while the value of dip is overestimated, though less than in the model [9]. The reason is that the model [8] has nonzero real part of the scattering amplitude coming from the Pomeron parametrization. However, the value of the real part is not enough for correct description of the dip value.

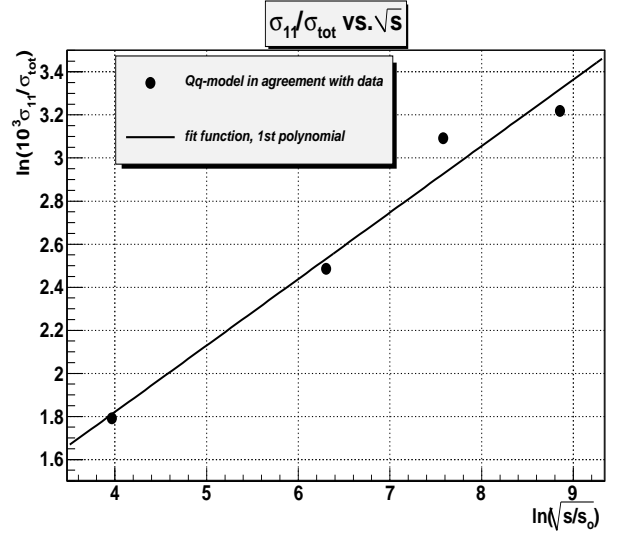


Fig. 5. The dependence $\ln(10^3 \sigma_{11}/\sigma_{tot})$ versus $\ln(\sqrt{s/s_0})$.

The model tuning with more sophisticated form-factors, investigation of additional sources for the scattering amplitude real part, and more broad comparison of the model with experimental data are current plans.

Acknowledgment

We are thankful to S. Giani for fruitful discussions of the paper contents. N.Z. is grateful to the DESY Directorate for the support within the Moscow – DESY project on Monte-Carlo implementation for HERA – LHC, he was also supported by FASI of Russian Federation (grant NS-3920.2012.2), the RFBR State contract 02.740.11.0244 and the Ministry of Education and Science of Russian Federation under agreement No. 8412. V.G and N.S. were partly supported by the CERN – RAS Program of Fundamental Research at LHC.

References

1. G. Antchev et al. (TOTEM Collaboration), *Europhys. Lett.*, **95** (2011) 41001; *CERN-PH-EP-2012-239*.
2. N.P. Zotov, S.V. Rusakov, V.A. Tsarev, *Fizika. Elementarnykh Chastits and Atomnogo Yadra*, (in Russian), **11** (1980) 1160.
3. I.M. Dremin, arXiv:1206.5474 [hep-ph]
4. D.B. Lichtenberg, I.J. Tassie, *Phys. Rev.*, **155** (1967) 1601.
5. P.J. De Souza, D.B. Lichtenberg, *Phys. Rev.*, **161** (1967) 1513; D.B. Lichtenberg, I.J. Tassie, P.J. Keleman, *ibid*, **167** (1968) 1535.
6. A.B. Kaidalov, *Z. Phys.*, **C12** (1982) 63; *Surv. in High Energy Physics*, **13** (1999) 265.
7. B. Anderrsson et al., *Phys. Report*, **97** (1983) 31.
8. V.A. Tsarev, *Lebedev Institute Reports*, **4** (1979) 12.
9. A. Bialas and A. Bzdak, *Acta Phys. Pol.*, **38** (2007) 159.
10. F. Nemes and T. Csörgö, arXiv:1204.5617 [hep-ph].

11. M. Bosso et al., *Phys. Letters*, **B147** (1984) 385; *ibid*, **B155** (1985) 197.
12. D0 Collaboration, *D0 Note 6056-CONF*.